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1 Title

A method and apparatus for finding a mobile radio terminal

2 Background to the Invention

2.1 Field of the Invention

The invention relates to systems or methods for finding a mobile radio terminal.

2.2 Description of the Related Art

A vital distinction is maintained throughout the following between on the one hand, the process of *locating* a mobile radio terminal and on the other hand the process which we will refer to as *finding* the mobile terminal. In the literature, locating a mobile terminal refers to the process whereby an estimate is made of the position of the mobile terminal. That process is affected by a variety of random errors and therefore the accuracy of such systems is measured in statistical terms which indicate the extent to which such an estimate is likely to vary from the true position of the mobile terminal. By contrast, the process we describe as finding a mobile terminal involves a person moving to the same position as the mobile terminal. The distinction may be understood clearly from the results of the two processes. Upon locating a terminal as described in the literature, one possesses an estimate of the position of the mobile terminal, which could be many hundreds of metres from the true position. Upon finding the terminal however, one has moved to exactly the same position as the terminal. As will be demonstrated later in this section, this distinction can be very significant when comparing the effectiveness of a location system as compared to a homing system for particular applications. For example enabling emergency response personnel to find an injured person in a timely manner.

To ensure clarity in the following descriptions, the mobile terminal that is being sought will be referred to as the *target device*. The terminal that enables the user to move to the position of the target device will be referred to as the *homing device*. The act of moving from a starting position to the position of the target device will be known as *homing*.

2.2.1 Homing Systems

The Prior Art contains many examples of homing systems. In the main these are based on radio or acoustic direction finding, in some cases with the use of a secondary indicator for the distance to the target. Such systems operate in a conceptually very simple fashion. The homing device detects a signal from the target device and measures the angle of arrival of the received signal. The user is

then advised to move in that direction. As with all radio signal measurements, the initial angle of arrival measurement will exhibit random errors. In principle however, as the homing device is moved towards the target device, repeated measurements enable the trajectory to be adjusted in such a fashion such that eventually the homing device comes to the *exact* location of the target device. Note that it is not necessary for a direction finding homing device to determine or be informed of its own absolute location or the absolute location of the target device. The device can operate solely in terms of the relative direction between the homing device and target device.

2.2.2 Location Systems

Also widely described in the Prior Art are location systems for mobile radio terminals. In some of these systems, the mobile terminal receives signals from a plurality of transmitters whose positions are known in order to determine the location of the terminal. Perhaps the best known example of such a system is the Global Positioning System (GPS) [HWLC94]. Another example is Cursor (US Patent No. 5,045,861). The Cursor system provides a means of locating mobile cellular telephones. The location determination is based on observations by the mobile of the time difference of arrival of signals from the base stations in the network. Both the GPS and Cursor systems involve the mobile terminal measuring the signals received from a plurality of transmitters whose positions are known. Such systems are known as self-positioning systems [Dra92].

The Trueposition system is another radio location system which provides a means of locating mobile cellular telephones [SKW94]. In this system a geographically dispersed array of receivers whose positions are known measure the signals transmitted from the mobile phone. Such systems are known as remote-positioning systems [Dra92].

2.2.3 Applications of Location and Homing Systems

As noted earlier, the primary function of a location system is to measure position in absolute terms, for instance within the GPS WGS84 global coordinate frame. The performance of such a system is specified in terms of such concepts as the error radius that includes 67% of the measurements. The performance of a homing system however might be specified in terms of the percentage of times that it enables users to find target devices. A useful homing system will be able to find the target a very high percentage of the time. Of course a radio location system could be used as a homing system, but this requires elaboration of the system, including communication of the estimated position of the target device to the user that is endeavoring to find that device. If the error in the position estimate is large, then the elaborated location system may not provide a method of actually finding the target device with any degree of certainty, and therefore

cannot be considered to be a useful homing system.

The application of radio location systems for locating mobile telephone subscribers has been an area of great commercial interest since the United States Federal Communications Commission (FCC) mandated that cellular operators provide this capability [FCC96]. The FCC has distinguished between self and remote positioning systems in specifying the required accuracy. For self-positioning systems, the required accuracy is 50 metres 67% of the time and 150 metres, 95% of the time. For remote systems the requirements are 100 metres 67% of the time and 300 metres 95% of the time. It should be noted that these statistical requirements apply on a wide scale, to entire cities for example. In particular areas, for example downtown, the performance could be much worse.

Given that the FCC mandate relates specifically to the task of dispatching emergency response personnel to E-911 callers, there is implicit in the mandate the intention for the positioning sytems to be elaborated upon and used as homing systems. It can be seen however that the accuracy requirements in the mandate do not provide the basis for a highly reliable homing capability. For the remote system, for instance, in 5% of the measurements, the estimated position of the mobile may be more than 300 metres from its true position. In an urban area, 300 metres is simply not sufficient to find a lost object or person, especially in an emergency when time is of the essence. Even the accuracy requirements for a self-positioning system fall short of the accuracy needed for an effective homing capability.

2.2.4 Factors Limiting the Utility of Radio Location Systems for Homing

The accuracy requirements in the FCC mandate, inadequate as they are for homing, reflect the current limits of technical feasibility for commercial, widely deployable, mobile telephone location systems. These limits are due to characteristics of terrestrial radio propagation including multipath (the arrival of multiple copies of the transmitted signal at the receiver), signal obscuration (commonly referred to in the literature as shadow fading) and near-far interference in which signals from a distant transmitter are blocked at the receiver by signals from a closer transmitter using the same radio channel. Multipath evidences itself as a bias in the timing observations made by a receiver. The bias is a function of the radio propagation path between the transmitter and the receiver. This bias translates into errors in the position estimate. The near-far interference and signal obscuration on the other hand result in a smaller number of transmitters being detected by the mobile in a self-positioning system (or a fewer number of receivers detecting the signals transmitted by the mobile in a remote-positioning system). The detection of fewer signals means fewer observations available for determining the location and a corresponding degradation in the accuracy.

The invention described herein provides a systematic method for effectively

operating a homing system in a mobile radio network, overcoming the factors that limit the effectiveness of location systems as homing systems. In theory of course it might be possible to overcome the accuracy limitations of a location system by making repeated independent measurements and averaging to reduce the error. In practice however the rate of error reduction with this type of averaging is at best slow. In many cases where the position estimates are biased the average will not converge to the true position at all.

2.3 Specific Examples of the Prior Art

The Prior Art contains many disclosures of how systems designed to provide the FCC mandated capability could be used as homing systems. In some of these descriptions, the authors assume that it is sufficient merely to provide the emergency response personnel with the output of the location system failing to address the poor accuracy inherent in urban and suburban areas which is likely to prevent or at least seriously delay the emergency personnel from reaching the mobile subscriber requesting assistance. Other disclosures show how to improve the accuracy of location systems in challenging radio environments. In the following paragraphs we review some of these, and show that while they may yield some improvement in accuracy, they nevertheless fail to lead to an effective means for homing.

US Patent no. 5,952,959 outlines a GPS based relative position detection system that could be used as a homing device. However this system provides no means to overcome multipath, near-far interference, and signal obscuration.

US Patent no. 6,049,304 describes a method of calculating relative position for GPS sytems that exploits that the fact that the errors are correlated for receivers that are in the same general area. However this invention is limited to GPS and requires an external positioning device (step 230 in the cited patent) and in any case the algorithm is not targeted at multipath type biases which typically have a correlation distance much less than GPS common mode errors.

US Patent no. 6,529,165 B1 notes that that in an network with unknown offsets between the basestations, a pair of receivers can measure their relative location more accurately than it is possible to measure the absolute location of either transmitter. However this effect is not due to multipath mitigation, but rather the use of common sets of BTS timing estimates by closely spaced mobiles. In order to operate in an unsynchronised network, this invention also requires five basestations to be received in common between a pair of receivers, making it vulnerable to areas with signal obstruction or or systems that experience near-far problems (such as CDMA).

US Patent no. 6,108,557 describes a method of locating a mobile by comparing the so-called radio frequency fingerprint for the mobile with a historical database. This invention might have the capacity of allowing mitigation of multipath errors, however it suffers from the drawback that an extensive field survey is needed in

order to build the database. As well, the actual nature of the observations can change on a minute by minute basis, due to objects moving in the vicinity of where the measurements were made, so making the database inaccurate.

US Patent no. 5,991,691 describes the use of a Kalman filter to smooth positioning measurements. However the kalman filter relates specifically to kinematic carrier phase tracking, and is not optimised for operation in a multipath environment.

US Patent no. 6,268,829 describes a method of direction finding suitable for locating a mobile telephone. In urban or suburban areas, it is unlikely that the searcher will receive a direct line of sight to the mobile, so that such a device would only work when the direction finder is close to the mobile. The patent does not disclose a method of coming within a suitable distance of the mobile.

3 Objects and Advantages

Besides the use of homing devices to find emergency callers, there are a large number of applications of such devices. These include finding stolen property, wandering pets, and lost children. Such a device could also be used to establish automatic navigational waypoints by locating mobile terminals at waypoints. Accordingly there are a wide variety of uses for a homing device that is able to operate effectively overcoming the challenges posed by radio propagation in environments such as suburban or urban areas.

The invention described herein provides a more effective capability for finding a mobile radio terminal (homing in on it) than anything disclosed in the prior art. It is able to do this because it can still find the target in the presence of multipath. In addition, it is able to find the target in cases where near-far interference and/or signal obscuration reduce the number of detectable signals to the point that conventional locations systems can no longer operate.

Compared to existing radio homing systems such as [Dop], the invention is able, in its simplest form, to operate with mobile cellular telephones without requiring any hardware modifications, and is able to find such terminals in suburban and urban areas.

When compared to the use of the True Position system for homing, the present invention has the advantages of greater reliability and the fact that the homing capability is available without requiring a substantial capital investment in the form of receivers throughout the network.

Compared to the remote positioning architecture of Trueposition, a self-positioning system such as Cursor requires substantially smaller capital outlay. However it does require a high level of participation from a number of mobile subscribers. Therefore a further commercial advantage of the present invention for offering a homing capability is that any single terminal can home in on a second terminal without requiring a large number of additional users to participate.

Furthermore while it may be possible to deploy a homing system based on the incorporation of a GPS receiver in the mobile terminal, a further technical and commercial advantage of the present invention is that it requires no hardware modification to a standard mobile telephone. As well, the invention can more accurately home in on a mobile terminal with a GPS receiver within it.

Further objects and advantages of our invention will become apparent from a consideration of the drawings and accompanying description.

4 Disclosure of the Invention

In the following paragraphs a series of methods are disclosed which can be used to implement an effective system for homing in on a mobile radio terminal. These methods can be applied in different combinations depending on the nature of the application and the technical and economic constraints that affect that application. To aid in understanding the different methods and the circumstances under which they could be used, we will arrange the possible homing applications into three groups according to the capabilities provided by the target and homing devices respectively, viz.

1. Target device measures selected attributes of radio signals and reports these to the homing system but homing device has no separate signal measurement capability
2. Both target and homing devices measure selected attributes of radio signals and report these to the homing system.
3. Target and homing devices measure selected attributes of radio signals and report these to the homing system. In addition, the homing device directly measures selected attributes of signals transmitted by the target device and supplies these to the homing system.

In general, the homing process can be concieved of as having two stages, a searching stage and a tracking stage. The searching stage applies in cases where the target and homing devices are unable to report sufficient common observations, i.e. observations of the same signals to enable their relative position to be measured directly. During this stage methods are used that enable the homing user to perform an efficient search for the target, with the aim of reducing the separation between homing and target devices to the point that sufficient common measurements can be made. Once sufficient common observations are available, the homing system enters the tracking process using the differences between common sets of observations to enable the homing device to converge more rapidly to the position of the target. Note that the search, if sufficiently exhaustive, can result in a successful finding of the target without the necessity of using the tracking stage.

4.1 First Aspect : If a target terminal has the capability to measure radio signal attributes but the homing device does not possess this capability

In a first aspect of the invention, the system provides a mobile terminal (the target device) that is able to measure selected attributes of signals received from geographically dispersed *network terminals* of the network serving that mobile terminal. (These network terminals may or may not be fixed in their position, however it is assumed that their position at any given time is accurately known). These measurements will hereafter be referred to as observations. The target device reports the observations to the homing system. As an example, the mobile terminal could be a cellular mobile telephone. In that case the network terminals would be the base stations of the cellular mobile network. Alternatively the mobile terminal could be a wireless LAN adapter. In that case the network terminals would be the fixed Wireless Access Points *check terminology in the 802.11 standard.* It is assumed that the location of the network terminals are available to the homing system. It is further assumed that when the mobile terminal reports an observation pertaining to a particular network terminal it also supplies information enabling the homing system to identify that terminal (in order to use the information concerning it's location). For example in the cellular network case, the ID of the base station would be supplied along with any observation.

We note that the homing *system* refers to the combination of the processing means for estimating relative position, selecting search routes etc. and the homing device. The homing *device* refers to the device carried by the user through which the system communicates with the user.

In the present aspect, the fact that the homing device does not have the capability to make measurements means that only searching methods can be applied. The homing system first uses a standard technique to decide if the target is moving or not. If the target is moving, the homing system is able to gather independent observations over a range of positions, filtering them to reduce spatially uncorrelated multipath biases. Such a set might to be sufficiently accurate that the homing device can provide directions enabling the user of the homing device to follow a route that will intercept the target. More often, the accuracy will be sufficient to be able to follow the progress of the target, allowing the User to wait until the target has stopped moving. There are strong public safety reasons for waiting until the target is stationary before trying to intercept it.

In the case when the target is stationary, (which in environments that give rise to heavily biased location estimates makes the target more difficult to find), the following strategy is employed. The homing system, uses the observations reported by the target device to estimate the most likely locations for the de-

vice (for example by calculating the probability density function (p.d.f) for the location of the target device). This p.d.f. Could be continuous but for ease of explanation we will assume it is in the form of a list of likely positions and associated probability values representing the likelihood that the target device is at the respective positions. The homing system then plans a route, that visits the most likely locations of the target first, but then visits increasingly less likely locations (taking into account the street topography). The route is communicated to the user of the homing device, by standard means, such as synthesized voice, text, or image. The user then travels the route looking for audio or visual signs of the target. By first visiting the most likely locations, the user of the homing device is likely to rapidly find the target. However, by following an exhaustive planned route, the user of the homing device will eventually find the target. It is a feature of this invention that typically the user interface will not indicate a position for the target, but rather a route to be taken to find the target. This form of interface will cause less frustration on the part of the user than an interface that presents a list of possible positions. This will in turn make it more likely that the user will follow an exhaustive search process and thereby succeed in finding the target device. The route planning process could optimise the route for such factors as street topography and geographical relationship of the likely positions. For example the distances between the possible positions and the associated probabilities of the target being at those positions could be used to select the route with the lowest expected distance.

It can be seen that a key element of this invention is the observation of signal characteristics related to the path (primarily the distance) between geographically dispersed terminals of the radio network whose positions are known and a target mobile terminal. Accordingly, the above invention also applies to mobile terminals that are equipped with GPS receivers that make observations of the time of arrival of signals from satellites. Similarly it also applies to remote positioning systems that make observations of the signals transmitted by the mobile at remote, terrestrial based receivers.

In some cases the homing system could be designed to perform relative position calculations and route selection etc. at an intermediate point and merely use the homing device as a means for communicating with the homing user. In this case the user may not even need a dedicated homing device but instead could use some other general purpose communications device to receive the directions. This could mean for instance that police requiring a homing capability could have the directions communicated via the existing police radio network thereby significantly reducing deployment costs.

As described above, the homing system in this aspect enables the user to move to the position of the target. A key inventive step is to calculate a set of likely positions and to provide the user with directions specifying an efficient search route. This route could be specified in a variety of terms depending on the capabilities of the homing device, in particular whether the homing device has an

independent positioning capability or not. For the case where the homing device does have an independent positioning capability (for instance a GPS receiver), the directions for the user of the homing device could be presented simply in the form of a relative direction in which to move (for instance an arrow on a screen also relying on the ability of the GPS receiver to detection current direction of movement). The directions could also be automatically updated as the user moves. However a simpler alternative is also viable. In this case the instructions could be presented to the user step by step in terms of local landmarks such as street names etc. The user could be asked to orient the device with respect to a particular street. The homing system would rely on the user to indicate when a particular step had been completed. This would be suitable for instance for people using the homing system in an area where they were familiar with the local geography. One such applications could be searching the streets surrounding one's home for a missing dog. The ability of the system to operate without requiring a positioning capability in the homing device would enable the cost of the homing device to be much lower and perhaps more in accord with the cost one might be prepared to pay for a device for occasional application such as finding a lost pet.

4.2 Second Aspect : If both the target device and homing device possess the capability to report signal observations

In a second aspect of this invention, which includes all the elements of the first aspect, the homing device also is equipped with a receiver capable of measuring the same types of network signal attributes as the target device. The homing system can use this additional information in a number of ways. In particular it enables the homing system to move from a search mode of operation to a tracking mode when there are sufficient common observations reported by the homing and target devices. This tracking mode can involve direct calculation of the relative positions of the homing and target devices. In the presence of common mode errors, this enables a more accurate computation of the relative positions than separately calculating the location of the target and homing devices and differencing the result. This process of measuring the relative positions using common observations is a key inventive step. In addition to the potential for accuracy improvement, the ability to compute relative position directly from a common set of observations enables the system to operate even in unsynchronised radio networks without requiring the use of pseudo-synchronising methods [DMS96]. Indeed this also means the homing system can operate effectively with fewer network terminals than is needed by the method and system described in US Patent No. no. 6,529,165.

This second aspect of the invention could also operate if the target and the homing device were equipped with GPS receivers whereby the GPS signal obser-

vations from the target and homing devices are provided to the homing system. (Note that the GPS receivers are being used to report timing observations, not to solve for position). It could also apply to a remote positioning system, in which case the homing device would be equipped with a mobile telephone transmitter that could be observed by the geographically dispersed receivers of the remote positioning system.

As discussed with reference to the first aspect above, the homing system could also be designed to have the signal observations communicated to an intermediate point, all the calculations done at the intermediate point, and then then the relevant navigation information communicated to the homing device.

A further feature of the present aspect is the provision of a means for the homing device to send a data message to the target device specifying a series of radio channels for the target device to measure and report. This enables the homing system to focus the measurement resources of the target device on the radio signals that can be heard by the homing device, thereby increasing the degree of commonality in the two resulting sets of observations.

4.3 Third Aspect : Filtering whilst the homing device is moving

A third aspect of the invention, which could improve the second aspect, takes advantage of the fact that the user of the homing device will be moving for a significant proportion of the time while homing in on the target device. While the user is moving the homing device is therefore able to gather independent measurements of the signal attributes that are varying randomly due to processes such as fast fading. By combining these in a standard way, such as a Kalman filter, the homing device can reduce spatially uncorrelated errors in the signal observations and achieve more accurate relative position measurements. If the homing device has an independent positioning capability, it is possible to average the estimates while the homing device is moving. If the homing device moves over a wide area and therefore a wide range of slow fading conditions the accuracy of the averaged estimates will improve. This process of wide area averaging is a key inventive step.

4.4 Fourth Aspect : Direct measurement by the homing device of target device signals

A fourth aspect of this invention, which would improve both the first and second aspects is to include in the homing device a means of detecting the signals transmitted by the target mobile terminal and measuring selected attributes of those signals.

This means would include a suitable radio front-end to receive the signals.

There would also be a provision for the target device to indicate the radio network channel parameters to the homing device, enabling that device to detect the signals. These channel parameters could include frequency, timeslot, serving network access point identifier and code. The advantage of a mechanism whereby the homing device directly measures the signal transmitted by the target device is that the accuracy of these measurements in positional terms increases rapidly as the homing device closes on the target device, providing an extra, highly accurate source of positional information, enabling even more rapid convergence of the homing system. The process of direct measurement to enable rapid convergence is a key inventive step.

Of course this facility will be much more easily implemented in radio networks where there is no duplex separation between terminal transmit and receive frequency bands. Examples include a UMTS network operating in TDD mode and a TD-SCDMA network. However in other cases technical and economic factors could also make the addition of this capability to the homing device useful.

A further improvement of this aspect would be to include a direction finding antenna in the homing device. In cases where line of sight propagation was possible between the target device and the homing device, the direction finding antenna could be used in a standard way to facilitate a very rapid convergence on the target.

In the case where the homing device is able to measure the time of arrival the direct signal from the target, then a further enhancement to this aspect is possible. The enhancement assumes that both the homing device and the target device is able to measure the round trip time to the same BTS. If the timing advance of the target is communicated to the homing device by a standard communications means (e.g. SMS), then it is possible to work out the range from the homing device to the target, the homing device to the common BTS, and the range of the target device to the common BTS. This provides the three sides of a triangle, or sufficient information to make a radial-radial location measurement [Dra92]. This measurement does not provide an absolute position fix, but does provide the relative location of the mobile. This relative location measurement will increase in accuracy as the homing device moves closer to the target. The relative location can be used in a similar fashion to the direction finding antenna to indicate the relative angle to the target (and also the range). In order to use this relative angle information, the User will need to be provided with an orientation, for example by a compass or by asking the user to align the homing device with a particular street.

4.5 Fifth aspect : User specification of target mobility

A further aspect of the invention is the provision for the user of the homing device to advise the system of the likely mobility of the target device. This additional information would enable particular constraints in the computation

of relative position solutions to be tightened, thereby increasing the accuracy of the computation. The application of this aspect can be understood from an example where a law enforcement officer is using the system to home in on mobile subscribers. In one example, the officer might be seeking to apprehend a stolen vehicle by homing in on a mobile installed covertly in the vehicle. In this case the target would be likely to be moving and the officer might not force the homing system to make any assumptions about the mobility of the user allowing it to determine that on the basis of the observations. By contrast if the officer was responding to an emergency call from the victim of a vehicle crash, forcing the system to treat the target as stationary could enable more accurate estimates of absolute or relative positions and therefore a more timely arrival at the scene of the accident.

5 Drawings

5.1 Brief Description of Drawings

- Figure 1 is a block diagram illustrating an example environment in which the preferred embodiment of the present invention is utilized.
- Figure 2 is a block diagram showing the main elements of a homing device in the preferred embodiment.
- Figure 3 is a block diagram showing the main elements of a target device in the preferred embodiment.
- Figure 4 shows the steps involved in the homing process of the preferred embodiment.
- Figure 5 is a block diagram showing the main elements of a homing device in the alternative embodiment.
- Figure 6 shows the steps involved in the homing process of the alternative embodiment.

5.2 List of Reference Numerals

- 2 BTS
- 4 BTS
- 6 BTS
- 8 BTS

- 10 Homing device
- 12 Target device
- 14 Mobile telephone network
- 16 Homing device user
- 20 Transmitter contained in homing device
- 22 Receiver contained in homing device
- 24 Processor contained in homing device
- 26 Map display contained in homing device
- 28 Transmitter contained in homing device
- 30 Man machine interface (MMI) in homing device
- 32 Transmitter contained in target device
- 34 Receiver contained in target device
- 36 Processor contained in target device
- 42 Detect movement method
- 44 Calculate p.d.f. method
- 46 Display route method
- 48 Filter observations method
- 50 Calculate proximity metric method
- 52 Use common mode differencing method
- 54 Display intercept route method
- 62 Uplink receiver contained in homing device
- 64 Directional antenna contained in homing device
- 72 Signal strength metric method
- 74 Direction finding method

6 Detailed Description

6.1 Preferred Embodiment

The preferred embodiment of this invention is shown in Figures 1,2 and 3 applied to a mobile telephone network whereby a user of the homing system is able to find a mobile telephone. Figure 1 depicts a segment of a mobile telephone network which includes a number of geographically dispersed BTSs, **2**, **4**, **6**, and **8**. There could be more or fewer BTSs. Also shown are a homing device **10** and a target device **12**. The homing and target devices are able to exchange data via the mobile telephone network, **14**. Note that although the BTSs **2**, **4**, **6** and **8** are typically considered part of the mobile telephone network, **14** is shown in order to represent the additional components of the mobile telephone network required to provide a communications facility between the homing and target devices. This exchange could be via a short message service (SMS) or other data exchange protocol supported by the network for instance a packet based data communication service supported by the network. The homing device is in the possession of a User, **16**, who is seeking to find the target device, traveling either on foot or via some other means of transport.

The main elements of the homing device are shown in Figure 2. It is comprised of a standard mobile telephone Transmitter, **20**, a mobile telephone Receiver, **22** that has been enhanced in order to make, upon demand, accurate measurements including received signal levels and timings for the broadcast channels of all BTSs that it can detect within its neighbourhood. The accuracy with which the receiver is able to measure the signal timings is of the order required for GSM E-OTD measurements as specified in Annex I of [ETS01]. The measurement reports would include information identifying the BTS corresponding to each measurement. For a GSM network for instance, this would be either the full Cell Id or alternatively the Short-Id. The receiver also provides the capability to optionally perform measurements on a specified list of radio channels. These channels could be specified in a message received from the homing device along with other measurement description parameters. The enhancements to the receiver could be in accord with those required to support a standard location system such as the Global System Mobile (GSM), Enhanced-Observed Time Difference (E-OTD). Alternatively the modification could be special purpose. The homing device also includes a general purpose computer or processor, **24**, such as is commonly found in mobile telephones. The homing device could also include a display, **26**, capable of presenting a map image. This map display is not essential, however it would provide a convenient means to convey route guidance information to the user. It should be noted that the map display would be implemented as a digital map displayed on a standard graphical screen. Accordingly the map display could also be used to convey other information to the user, such as an arrow indicating compass heading. A further optional element of the homing device

would be a compass, **28**. Such a compass could be of solid state construction, providing a small and cost effective implementation. This compass would enable a map display to be optionally oriented correctly with respect to the ground, aligned with true north regardless of the orientation in which the user rotated the device. Such as compass would also enable relative bearing indications for the target to be presented consistently irrespective of rotation of the device by the user. The homing device also includes a man machine interface (MMI) such as commonly provided in mobile telephones which enables the user to optionally input information concerning the likely mobility of the target device.

The main elements of the target device are shown in Figure 3. It contains a standard mobile telephone transmitter, **32**, a mobile telephone receiver, **34**, that has been modified in a similar fashion to the mobile telephone receiver in the homing device, **22**.

With reference to the earlier disclosures, this preferred embodiment corresponds to the case described in section 4.2, namely where both the homing and target devices have the capability to measure attributes of signals transmitting by a serving mobile radio network.

The steps used in the method for the homing device to find the target device are shown in figure 4.

42 Detect Movement The Homing Device processor **24** receives measurements of the received signal timings and signal strengths (the observations) measured by the target device receiver, **34**. The Homing Device processor **24** can determine if the target device is moving using techniques well known to those skilled in the art. For example it could inspect the sum of squared differences between observations made at two different time periods and use a statistical test to determine if there is a signficant change. If movement is detected, then the method would use step **54**, otherwise it assumes the target is stationary and goes to step **44**. Alternatively if the user of the homing device has specified that the homing system should treat the target device as stationary, the method would use step **42**, which is the start of the search strategy.

44 Calculate p.d.f The homing device, **10** will receive timing and signal strength measurements from the target device, **12**. If the network is synchronised or the offsets are known (as could be done with the method described in US Patents 6,529,165 B1 or by the E-OTD standard), then it is possible to calculate an estimate of the target device position based on the timing measurements. Using methods known in the Prior Art it is possible to estimate the p.d.f for the position estimate. For example, a method with only a small computation load would be used to calculate the error ellipses, assuming that the errors are gaussian and the position equations can be linearised near the true position of the target device. A more accurate technique would involve the use of a bootstrap method [ZB98]. This could

involve a technique such selecting at random quartuplets of common timing observations from the set of all available observations. Each quartuplet can be used to calculate a unique position estimate. The sample distribution of these quartuplets will give an indication of p.d.f of the target device position. This p.d.f. Can be discretised to yield a list of possible positions, with corresponding probabilities.

If the network is not synchronised and the base station timing offsets are not known, the signal strength measurements can be used to make a less accurate estimate of the target device position. Several methods are described in the open literature for making such measurements, for example [HMM97]. This type of method is commonly referred to as a Cell-ID positioning method. Error ellipses and a modified bootstrap method can also be used to calculate the p.d.f. in this case.

46 Display Route Based on the p.d.f calculated in **42**, it is possible to determine a route that will visit the most likely locations of the target first, and then progressively move to less and less likely locations. A simple example of such a route would start at the most probable position, and then move outwards in concentric ellipses, having regard to the pattern of the streets. This route information could be displayed on the map display, **26** of the homing device, **10**. It could also be provided to the user by textual or audio messages.

48 Filter Observations Whilst the homing device, **10** moves, the observations can be filtered using a method that accounts for movement. Such filters are well known to those skilled in the art. An example is the Kalman filter. This filtering provides a more accurate estimate of the timing and signal strength. The observations from the target device, **12**, can be filtered in a similar fashion, in this case taking into account the decision made in step **42** concerning the mobility of the target device. Whilst carrying out this step, the user, **16** of the homing device, **10** is assumed to be progressing along the route defined in step **46**.

If the homing device has an independent positioning capability then the absolute positions inferred by the relative position estimates can be averaged. If the homing device moves over a wide areas this should improve the accuracy of the resulting estimates.

50 Calculate Proximity Metric The calculation of the proximity metric will only include observations of the BTSs that are reported by both the homing device **10** and the target device **12**. This subset of the observations will be referred to as the in-common subset. For example, if a particular BTS is observed by the homing device but not the target device, then the measurements by the homing device of that BTS would not be included in the

in-common subset. The proximity metric could take a number of forms, the simplest would be the weighted sum of squares between the filtered estimates of timing and signal strength from the homing device and the filtered estimates of timing and signal strength from the target, divided by the number of BTSs in the in-common subset. The weighting would take into account the estimates of the variability of each of the observations.

More sophisticated versions of this metric are possible. For example, if N is equal to the number of BTSs in the in-common subset, then instead of dividing by the weighted sum of squares by N, it would be possible to divide by a non-linear function of N. The non-linear function would be chosen to increasingly reduce the size of the metric as the number of BTSs in the in-common subset increases. Such a function would be N^2. This non-linearity is based on the obvious phenomenon that as the homing and target devices move closer to each other they are increasingly likely to detect the same BTSs.

If the proximity metric indicates that the target device and the homing device are close to each other, then the method would enter tracking mode by the use of step **52**, otherwise the method would use step **48**.

52 Use Common Mode Differencing Once it is determined that the homing device and target device are close to each other, then it becomes possible to more accurately calculate the relative position. This is due in part to the possibility for eliminating common mode errors in the homing and target device observations, particularly relating to multipath biases. In the GPS Prior Art several methods are disclosed for calculating the relative position in such a situation, some of which would be applicable to this situation. The simplest method is to continuously make position estimates using the observations from the homing device but limit the observations to the in-common subset. Similarly a position estimate can be made using the observations from the target device, using only the in-common subset. The relative position is calculated by taking the vector difference between the two position estimates. Alternatively the relative position can be calculated directly which can require a smaller number of network terminals.

Because the common mode differencing is able to provide a more accurate relative position determination, the user may be instructed to abandon the pre-determined route, and follow a direction indicated by the relative location from the homing device to the target device. This modified set of directions could be indicated on the map display, **26**, or given as audio or visual cues via the MMI **30**. If the homing device includes a compass, **28**, the direction could be provided in terms of a suitable indicator on the map display, whose orientation is adjusted according to the relative bearing to the target device and the orientation of the homing device display at the

time.

The proximity metric can be re-calculated a suitable intervals to monitor the progress of the homing device towards the target device. If the proximity metric indicates that the homing device and the target device are diverging, then the user can be directed back to the predefined route (or a suitably modified version of the predefined route), and the method recommences with step **48**.

If the proximity metric continues to indicate that the target and homing device are converging, then the method continues with this step, **52**. As the homing device continues to approach the target device, an audible or visual indication of the estimated distance to the target could optionally be provided to the user. As this process continues, the relative position measurements become increasingly accurate, and in short order user of the homing device establishes visual contact with the target device and the method is considered complete.

54 **Display Intercept Route** Generally, for public safety reasons, it is best not to intercept a rapidly moving target. In this case it is best to follow the target device at a distance and wait until the target device has ceased movement. Once this has happened the method continues with step ???.

If both the target device and the homing device are moving, then the observations can be filtered to reduce spatially uncorrelated errors such as those due to fast fading using a method that accounts for the movement of the devices. Such filters are well known to those skilled in the art. An example is the Kalman filter. If the network is synchronised or the offsets between the various BTSs are known, then the filtered timing observations can be used to calculate the positions of both the target device and the homing device. Otherwise the signal strength observations can be used in a Cell-ID type calculation to obtain lower accuracy estimates of the positions of the target device and the homing device.

A suitable route to the target can be calculated, as described for step 46. The route can then be displayed on the map display **26**. As the positions of the homing device and the target devices change, suitable updates can be applied to the display of the recommended route. In some circumstances this step will result in the homing device finding the target before it becomes stationary.

6.2 Alternative Embodiment

An alternative embodiment is described in the following paragraphs featuring a homing device, **10**, which is modified to provide the capability for directly reception of signals transmitted by the transmitter, **32** in the target device. The

main elements of the modified homing device are shown in Figure 5. These include **20,22,24,26 and 28**, all the components of the standard homing device (Figure 2). In addition an uplink receiver, **62**, is provided, having the capability to receive signals originating from the target device transmitter, **32**. The modified homing device also includes a directional antenna **64**. In the alternative embodiment, the target device is able to send to the homing device, via the mobile network, **14**, information pertaining to its own transmission including the radio channel parameters. In this manner the uplink receiver, **62** is able to directly obtain observations of the signals transmitted by the target device. It should be noted that for the purposes of describing this alternative embodiment, we have assumed that in this radio network, the uplink and downlink frequency bands are distinct necessitating a separate uplink band receiver **62**. Clearly for networks where this was not the case, this uplink reception capability could be provided by the existing receiver, **22**.

The method of the Alternative Embodiment is shown in Figure 6. It includes the steps, **42,44,46,48 and 54** as in the Preferred embodiment (shown in Figure 4). However it includes new steps, **72 and 74**. In general terms, the method follows the same procedure as described in Figure 4, differing only in the way in which the tracking stage is implemented. In particular, instead of using the proximity metric described in the preferred embodiment, it computes a different proximity metric using the additional direct measurements of the target device transmissions in addition to the other in-common observations. When the processor, **24**, in the homing device decides that the range to the target device is sufficiently small for a high probability of line of sight to the target, the homing device then employs the directional antenna to obtain a direct measurement of the bearing to the target. The homing device processor does not use the directional antenna until it has a strong indication of line of sight, otherwise it is likely to give an incorrect indication to the user.

We will now describe in detail the alternative embodiment by defining steps **72** and **74**.

72 Range Metric The homing device's uplink receiver, **62**, is able to tune to the radio channel in use by the target device transmitter, **32**. The homing device uplink receiver can use means well known in the prior art to measure the received signal strength and time of arrival. If the homing device has current information on the current transmission power level of the target device transmitter, the homing device can determine the degree of attenuation in the path from the target to the transmitter. Then, using a suitable empirical model, it can estimate the range to the target. If the homing device has a means of measuring the range to the target by use of a timing measurement, then it should work out the range between the homing device and target. If the range can be estimated using timing measurements, then such a range measurement will be preferred to the range inferred from

signal strength. However, using methods well known in the art, it could be possible to combine the two estimates into a single estimate of range.

In either case (signal strength or time of arrival), the homing device can then use the calculated range as a metric for determining whether the target device was nearby. There are a number of ways in which this could be done. One simple way is to determine whether the range is below some *initiation* threshold. If so, then the homing device would be considered to be close to the target device. If the measure used indicates that the homing device is in close proximity to the target device, the alternative method goes to step 74. If on the other hand the metric indicates that the homing device is not yet close to the target device, then the alternative method goes to step 48.

74 **Direction Finding** There are two possibilities here, the first is if only a signal strength estimate is available, and the second is if a range can be calculated from the time of arrival:-

Signal Strength Only The homing device could indicate to the user, via an audio or textual or graphical prompt, that the device has entered direction finding mode (i.e. tracking mode). In this mode, the directional antenna, **42**, is switched into the signal path of the homing device's receiver, **11**. As well an audible or graphical indication of range (as derived from signal strength) is provided to the User, **8**. In a manner that has been described often before in the prior art, the User rotates the homing device with the rigidly attached directional antenna, and by paying attention to the range indication, moves in the direction of minimum range. The method continues in this mode until the target is found, or the range increases above a *desist* threshold (which might be different from the initiation threshold). Increasing above the desist threshold could be an indication that the homing device is no longer close to the target device, in which case the method of he alternative embodiment would revert to step **48**.

Range is available from Time of Arrival In this case, as well as the range, the homing device can calculate the relative location of the target. This information is then used in a similar fashion as is described in step **52**, with the range metric used as the proximity metric

7 Figures

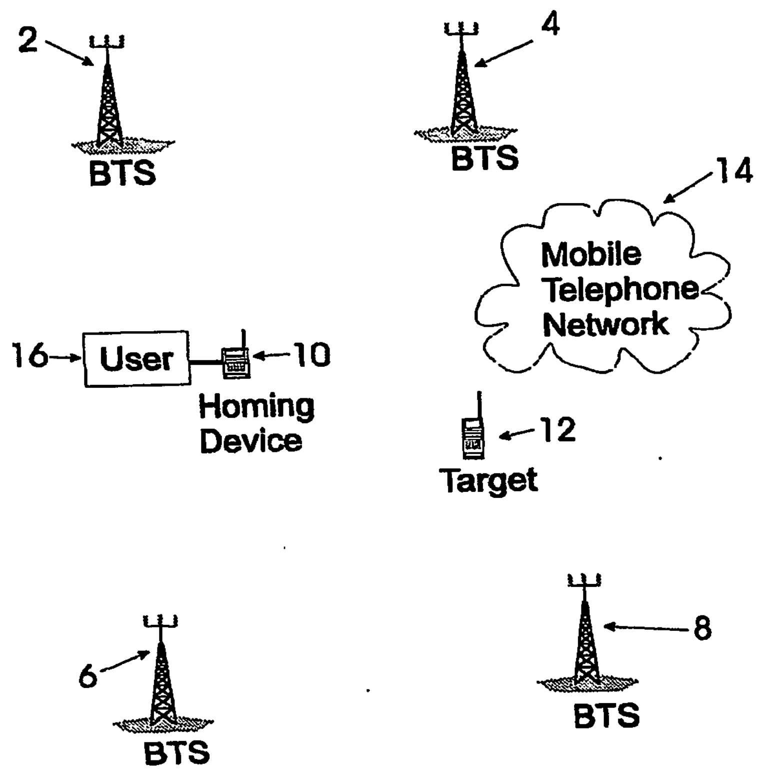

Figure 1: Illustration of the preferred embodiment whereby the homing system is applied for the purpose of finding a mobile telephone

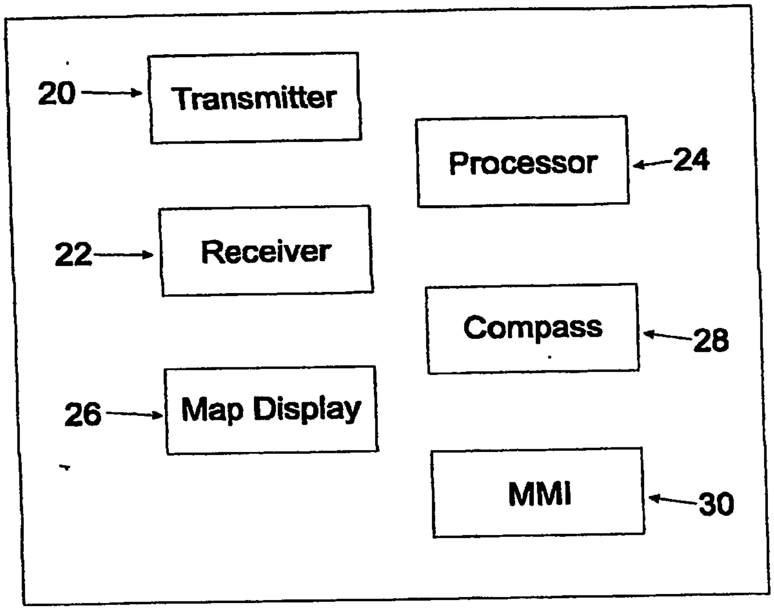

Figure 2: Main elements of a homing device

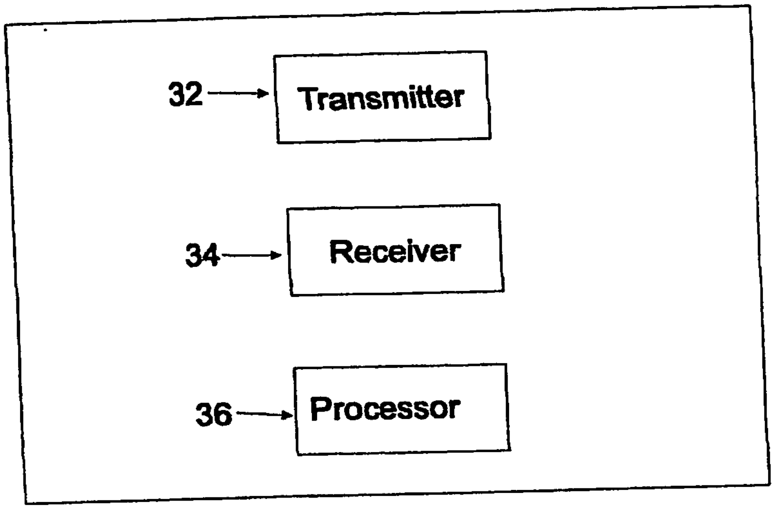

Figure 3: Main elements of a target device

8 Conclusions, Ramifications, and Scope

While our above description contains many specificities these should not be construed as limitations on the scope of the invention, but rather as an exemplification of one preferred embodiment thereof. Many other variations are possible. For example:

- The invention has been described in terms of a method, but could also be embodied as a system.
- The invention could be implemented in remote systems such as Trueposition as an application add on. In this case, the remote positioning system would be instructed to make timing measurements of the target mobile terminal, and the homing device. These measurements would then be used by a central site in the remote system in a similar manner as the preferred embodiment in order to allow the user of the homing device to move to the terminal.
- The invention could be implemented in self-positioning systems such as E-OTD as an application add on. In this case, the mobile terminal in the homing device and the mobile terminal in the target would be instructed to report their timing measurements to a central site. These measurements would then be processed at the central site in a similar manner as the preferred embodiment to allow the user of the homing device to move to the terminal.
- The exact sequence of steps in the preferred and alternative embodiment could be varied to still bring about the same effect. For example with multi-tasking system, some of the steps could be performed in parallel.
- The system can also improve the performance of Assisted GPS systems. For example, if both the target and the homing device contain AGPS receivers, then the AGPS timings can be used in a similar fashion to the observations described in the preferred embodiment.

Our invention has significant advantages to the existing ways of homing in on mobile terminals.

Compared to remote location systems such as Trueposition that are used to locate mobile telephones, the technology provides a more reliable and and lower cost method for locating mobile telephones. The invention can also add an effective homing capability to such existing location systems.

Compared to self location systems such as E-OTD that are used to locate mobile telephones, the technology provides a more reliable and and lower cost method of locating mobile telephones. The invention can also add an effective homing capability to such existing location systems .

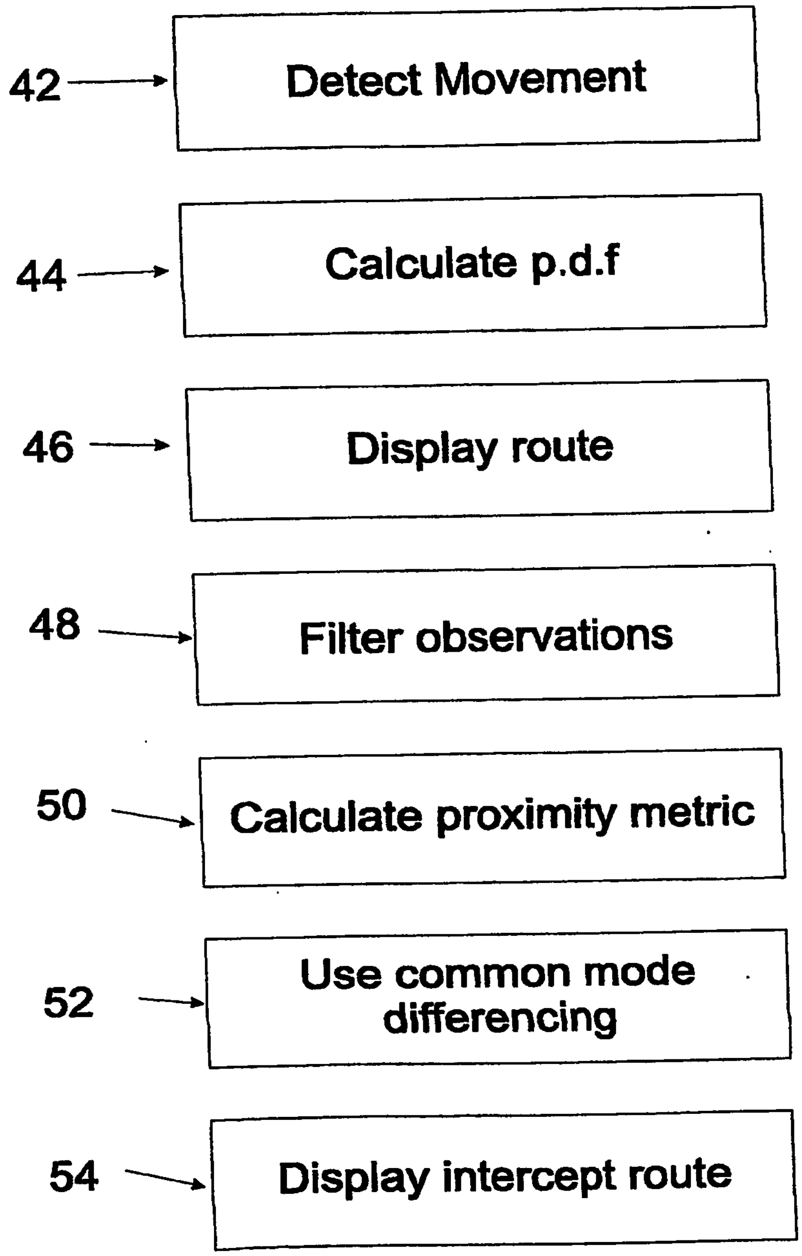

Figure 4: Illustration of the steps used in the method of the preferred embodiment for the homing system to find the target device

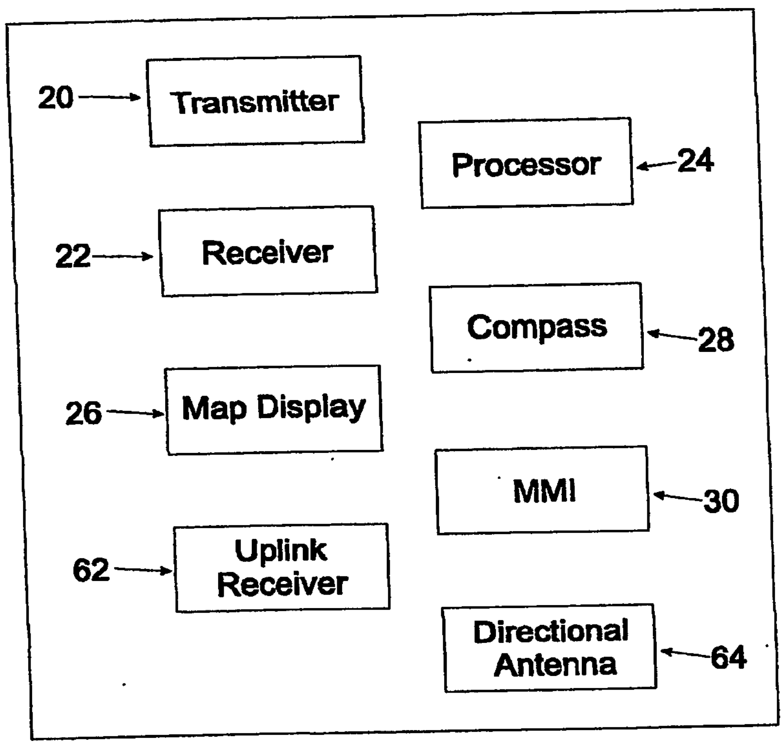

Figure 5: Main elements of a homing device having the optional capability to directly measure signals transmitted by the target device

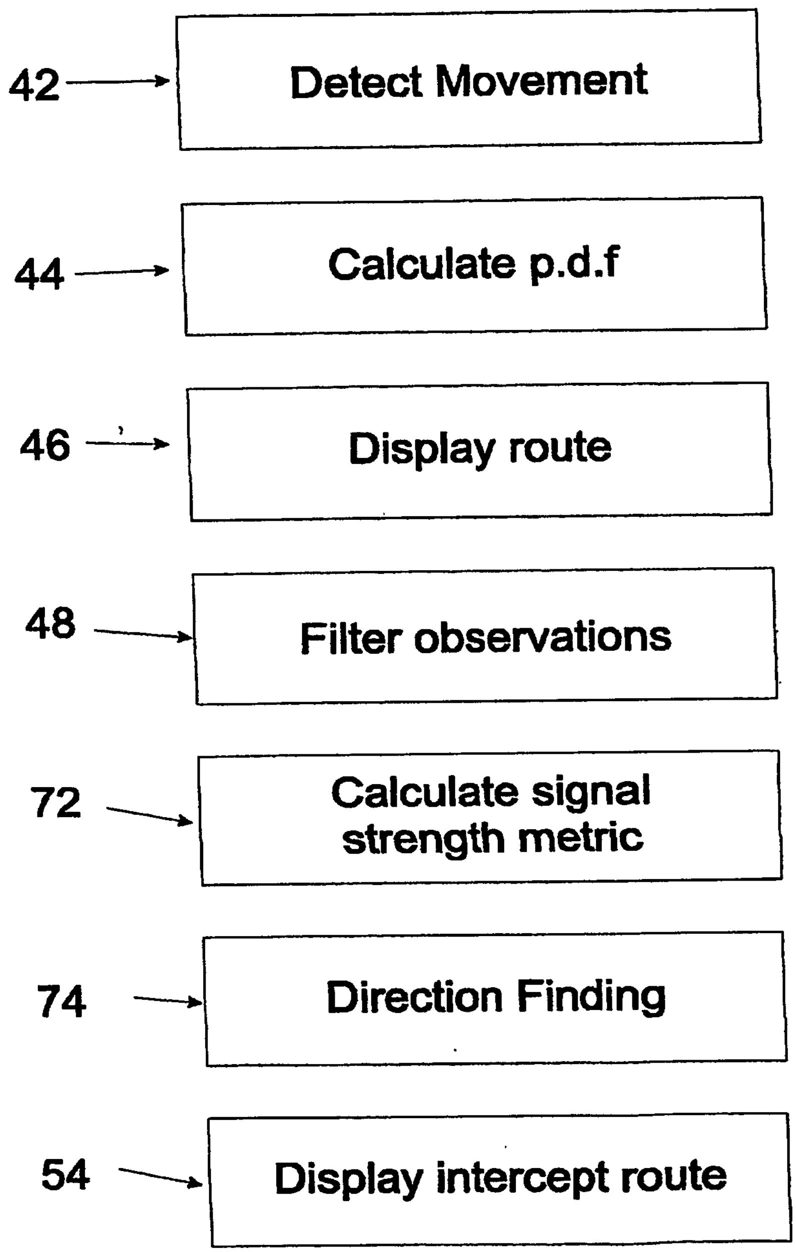

Figure 6: Illustration of the steps used in the method of the alternative embodiment for the homing system to find the target device

Compared to Assisted GPS systems [BMMR02], in its simplest form, our invention requires no hardware modification to a cellular telephone, and therefore is more cost effective. As well it will have superior homing performance in urban and suburban areas.

Compared to direction finding type systems such as that described in [Dop], our invention is less bulky, less expensive, able work with little or no modification to the mobile terminals, and is able to operate effectively in suburban and urban areas where non line of sight conditions exist.

In summary, this invention provides a highly reliable and inexpensive method of homing in on a mobile terminal. It's performance is particularly advantageous for terminals operating in suburban and urban areas. It has a wide variety of applications, including the finding of lost pets, recovery of stolen property, provision of navigational waypoints, and response to emergency calls. In the United States the invention is likely to have important public safety implications in regard to improving the performance of the FCC mandate cellular telephone location systems for successfully finding mobile subscribers.

9 Abstract

A method and apparatus is disclosed for finding a mobile radio terminal. A homing device is seeking to find a mobile radio terminal. Based on observations related to the mobile terminal's position, the homing device uses a two stage method to move to the same position as the mobile terminal. The first stage involves developing a exhaustive search strategy that is based on estimates of the most likely position of the mobile terminal. If the homing device is also able to make observations related to its own position then the second stage involves make relative position measurements which become more accurate as the homing device approaches the mobile terminal. In this way the user of the homing device is guided to the exact position of the mobile terminal. A number of other enhancements are described including the use of direct measurement of signal strength, angle of arrival and timing to aid the process, and the use of prior information concerning the stationarity of the mobile terminal.

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